Final Report
ATS SINGLE SIDEBAND
AFC CARRIER OFFSET STUDY

RAYTHEON COMMUNICATIONS & DATA PROCESSING OPERATION
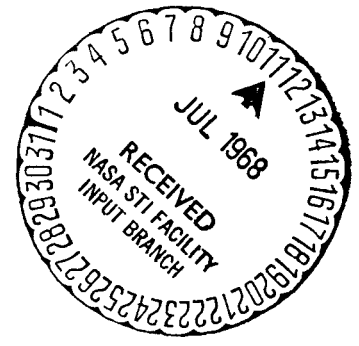
Final Report

for

ATS SSB AFC Carrier Offset Study

(13 April, 1966 - 27 July, 1966)

Contract No. NAS 5-10176

prepared by

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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Goddard Space Flight Center

Greenbelt, Maryland

ABSTRACT

A study performed to develop a plan for increasing the range of the ATS SSB AFC so that in addition to tracking a satellite with a doppler shift of ±35 kc the system is capable of acquiring and tracking a space craft with a carrier offset as high as ±180 kc.

An initial design study is reported and alternative solutions advanced.

A recommended solution employing a wide range, low noise VCO is proposed along with results of a feasability test on a VCO. The physical implementation within the ATS-SSB Transmitter is described, and a field change procedure is recommended.

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1. INTRODUCTION

As part of the National Aeronautics and Space Administration's Applications Technology Satellite (ATS) program, Raytheon's Communications and Data Processing Operation (CADPO) has designed and manufactured (under contract no. NAS 5-3464) a closed-loop automatic frequency control system with a doppler correction capability of more than ±30 kc. The closed-loop scheme was required by the GSFC for use with either a synchronous satellite or a medium altitude (6000 miles) satellite.

The purpose of the following Carrier Offset Study is to develop a plan for increasing the range of the ATS SSB AFC so that, in addtion to tracking a satellite with a doppler shift of ±30 kc, the system is capable of acquiring and tracking a spacecraft with a carrier offset as high as ±180 kc

There are several problems involved due to the present design of the system. The need for added circuitry does not alter the signal to noise requirements of the system. This dictates the use of oscillators with low rms deviation, and requires that mixing frequencies and oscillator purities be chosen with these factors in mind. Readouts and controls must be provided to permit operation of the system, and it is desirable to place these on the console. Finally, to reduce interfacing problems and to simplify changeover, the modifications should fit inside the existing SSB exciter rack.

Raytheon and NASA-GSFC technical personnel, at the GSFC meeting of 13 April 1966, reviewed the causes and extent of the problems involved and defined most of the guide lines for possible solutions.

This report presents the problems outlined at the meeting and Raytheon's proposed solutions and recommendations resulting from a comprehensive and objective study.

2.   SCOPE

A.   Problem.

The problem stated by the GSFC to the Raytheon engineers was as follows: the 16 mc oscillator in the spacecraft has three frequency dependent characteristics;

	Specification Limits
Basic accuracy	±10 ppm
Long-term aging	±5 ppm
Temperature coefficient	±4 ppm/10°F

These add up to a maximum of ±170 kc tolerance at 6300 mc.

(1)   Basic accuracy.

Inaccuracy of ±10 ppm represents a ±63 kc potential offset between the reference carrier frequency from the ground and the LO frequency at the satellite converter mixer. It was stated that Hughes has been able to reduce this to less than 10 cps at 16 mc (4 kc at 6300 mc). Therefore, it was Raytheon's understanding to use this number for the purposes of the study.

(2)   Long-term aging.

Insufficient life test data was available from Hughes, but it was expected that the ±5 ppm would be met.

(3)   Temperature coefficient.

The oscillator is designed for a nominal operating environment of 70°F. It is not in an oven. When the satellite is spin stabilized, the ambient at the oscillator is relatively constant, and is expected to be close to 70°F. When

the satellite is gravity-gradient stabilized, two things cause the ambient to change. First, whenever the earth passes between the sun and the satellite, the temperature can change drastically. It is not known what the time constant or the thermal lag characteristics are but it is expected that the ambient temperature could go as high as 100°F and as low as 40°F as a result of the maximum eclipse time of 90 minutes at synchronous altitude. The eclipse time for medium altitude was not stated, but is appreciably less. Secondly, if the oscillator is not at the center of the spacecraft, its ambient will change as the sun shines upon different parts of the outer surfaces. This variation is cyclic, but is expected to remain within the 100°F to 40°F range stated above.

B. Assumptions.

Some simple but crude assumptions were made in an attempt to establish the characteristics of the correction scheme that might be employed in compensating the fixed and cyclic frequency variations. From the data, it appears that the variations due to temperature are dominant, especially since they will change in a cyclic manner with a relatively short period. It was assumed that a typical temperature coefficient will result in a 90 kc change in frequency, taking 90 minutes to occur (the full eclipse time), and if the rate of drift is linear, it is 1 kc per minute or 16 cps.

NOTE

It was stated that the measured drift rate of the oscillator to a step change in temperature was 2 cps per second at 16 mc or 800 cps per second at the LO frequency. However, the thermal lag between the outer surface and the oscillator ambient will undoubtedly significantly reduce the rate of change of temperature at the oscillator.

If a correction were to be made for each 15 kc of change, this means a correction each 15 minutes. It was stated by the GSFC that such a correction rate was acceptable.

A second assumption is that when the satellite is at synchronous altitude, so that the eclipse time, and hence the temperature variation, is at a maximum, the doppler is very small; and when the satellite is at medium altitude, where the doppler is high, the eclipse time is short, and hence the temperature variations are small. Thus, adding the doppler shift and other causes of carrier offset together at their maximums is not realistic.

In summary, it was found that a ±150 kc offset compensation is realistic. In this study Raytheon was permitted to use this figure if there was a significant cost saving compared to the 210 kc figure.

The 150 kc was derived as follows:

Case A: Synchronous Altitude

Doppler	0 kc
Basic accuracy	5 kc
Long-term drift	30 kc
Drift due to temperature	60 kc
Safety margin	55 kc
	150 kc

Case B: Medium altitude

Doppler	35 kc
Basic accuracy	5 kc
Long-term drift	30 kc
Drift due to temperature	30 kc
Safety margin	50 kc
	150 kc

The measured data on two oscillators was as follows:

Temperature	Osc. A	Osc. B
40°F	16.581637 mc	16.347738 mc

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Temperature	Osc. A	Osc. B
70°F	16.581495 mc	16.347622 mc
100°F	16.581379 mc	16.347510 mc

C: Study Guidelines

Study guidelines established in addition to the afore-mentioned were as follows:

(1)   First time acquisition by one station at a time is permissive.

(2)   Reacquistion by each station for each pass of the medium altitude satellite should not require a complete first time acquisition procedure, if first time acquisition is complicated and time consuming.

(3)   The operator should be notified by either predetermined calculations or alarms when it is time to make a correction.

(4)   Manual correction in 15 kc or 30 kc increments is permissive.

(5)   The frequency meter readout should still be usable so that either a total offset figure is displayed, or the sum of the display plus the dial indication, for the fixed compensation, gives the total offset figure.

(6)   An increase in system noise or degradation of other performance parameters is to be avoided unless the cost involved is prohibitive.

(7)   For use in determining expected offset (as an aid in acquisition and switching between two transponders), measurement of spacecraft oscillator data will be made available to the sites.

(8)   Hardware implementations may consist of purchased or fabricated units externally mounted to the transmitter.

3. TECHNICAL DETAILS

A. Initial Design Study.

The following conclusions were derived from the aforementioned scope of the problem.

(1) The offset was made up of a static portion and a dynamic component.

(2) The dynamic component is made up of the relatively fast-changing doppler shift, the slower shift due to temperature change at the spacecraft oscillator, and the very slow variation from long-term aging of the oscillator.

(3) The static component is due to the initial inaccuracy of the space-craft oscillator.

The doppler shift is corrected by the existing afc circuitry. However, a further adjustment is necessary. This correction must be of a tracking nature in the case of temperature variations, but could be a predetermined constant in the case of the basic accuracy and long-term drift components.

Tracking Corrections	Synchronous	Medium Altitude
Doppler	3 kc	35 kc
Temperature	60 kc	30 kc
	±63 kc	±65 kc
Non-Tracking (Static) Corrections		
Basic accuracy	5 kc	5 kc
Long-term drift	30 kc	30 kc
	±35 kc	±35 kc

Because of the narrow bandwidth of the afc preselector filter (300 cps wide), if a step-type correction is made to the carrier frequency the system

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Then
$$\frac{V_o(s)}{V_i(s)} = \frac{G/\tau}{s + \frac{G+1}{\tau}}$$

If a ramp $V_i(t) = At$ is applied, the output will be:

$$V_o(t) = \frac{AG}{1+G} \left[t - \frac{\tau}{1+G}(1 - e^{-\frac{G+1}{\tau}t}) \right]$$

The maximum error will occur as $t \gg \frac{\tau}{G+1}$ and the exponential term goes to zero. In the steady state (for ramp input) the output will be

$$V_o(t) = \frac{G}{1+G}(At) - \frac{AG\tau}{(1+G)^2}$$

If G is 60 db, as in the ATS AFC,

$$V_o(t) \approx At - A\frac{\tau}{1000}$$

For the AFC, $\tau = 590$ seconds, so

$$V_o \approx At - A(0.59)$$

Since $V_i = At$, the error is

$$\epsilon = 0.59A$$

If we are to keep ϵ less than 100 cps (for safety's sake), the sweep rate coefficient A must be less than 167 cps/sec. As long as the correction scheme does not exceed this frequency correction rate, the afc will remain in lock and the system will remain operational.

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will go out of lock and have to reacquire. It is assumed that this is undesirable, since communications is lost during this time. Initial acquisition is not a problem, since records would be accessible to indicate where (in frequency) to search. The problem is to stay in lock during a pass.

The existing afc has an operating range of ±50 kc over which it will perform corrections and stay in lock. The search will lock it in over ±35 kc.

The best tactic for acquisition would be to manually set the frequency of the transmitter so that the returned Fp pilot from the satellite to be acquired is within ±30 kc of the correct frequency. The afc search would then be activated, locking in on a medium-altitude spacecraft within one minute and on a synchronous satellite within two minutes.

Because of the necessity for tracking over a larger range than that covered by the afc, and because reacquisition for a change in frequency is not permitted, it will be necessary to change the range in a manner slow enough so that the afc loop can keep up without having the pilots fall out of their 300 cps-wide filters. The following is a method for slowing the change.

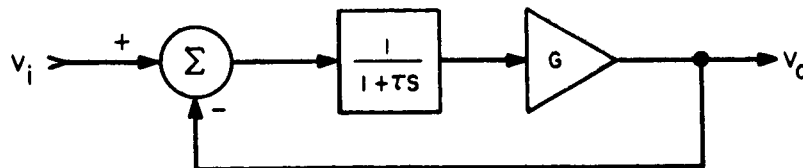Assume the afc loop is represented by the equivalent linear system shown in figure 1.

Figure 1. Equivalent Linear AFC System, Simplified Block Diagram

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It is proposed that several ranges of afc center frequency be set up
(-180 kc, -120 kc, -60 kc, 0, +60 kc, +120 kc, +180 kc). When the frequency
correction by the closed loop afc reaches a high value (±35 kc) the system
would switch to the next offset range. The switch would be gradual, about
six minutes duration. A time chart of a typical cycle is shown in figure 2.

The afc system is thus automatically kept within its operating range even
though the frequency offset may be several times this range. The implementa-
tion of this scheme may pose several problems; the most difficult being the
problem of keeping the carrier rms deviation less than one cps rms.

Using the implementation scheme of figure 3, the rms deviation of the
output 85 mc carrier would meet the requirement if the deviations of the two
VCXO's could be held to less than 0.7 cps rms each. The 15 mc VCXO's
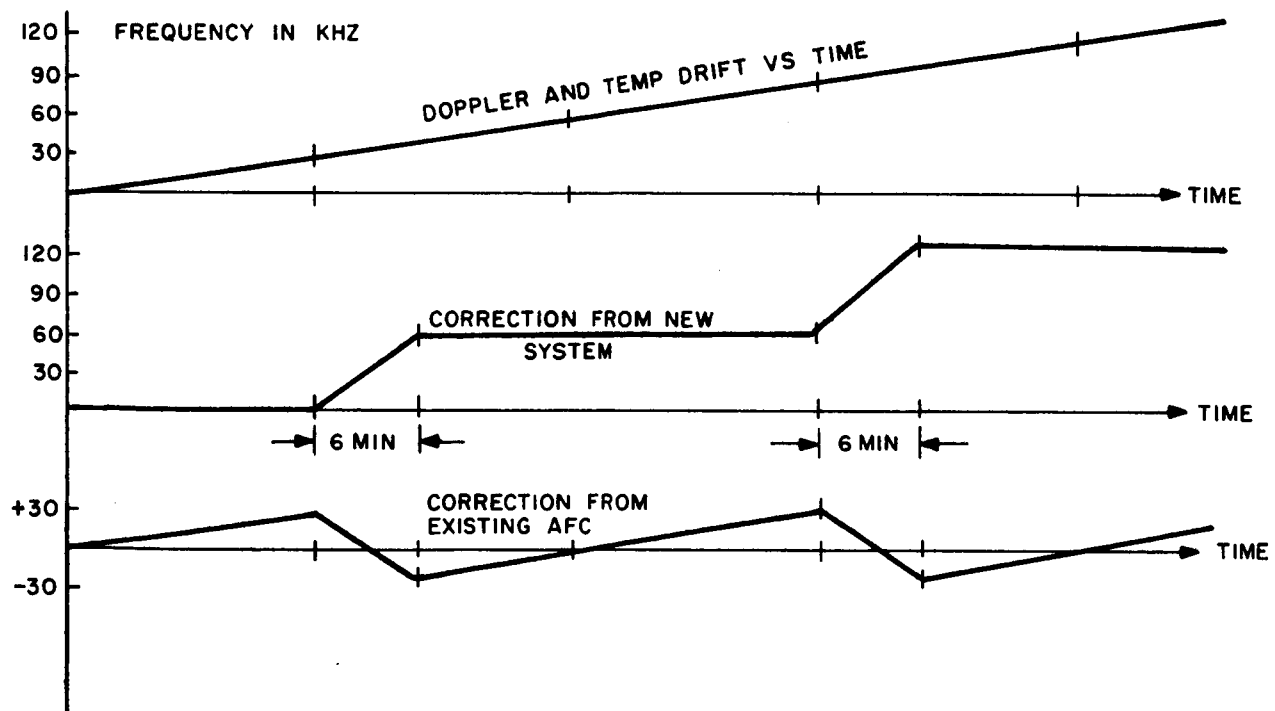are well within this figure.

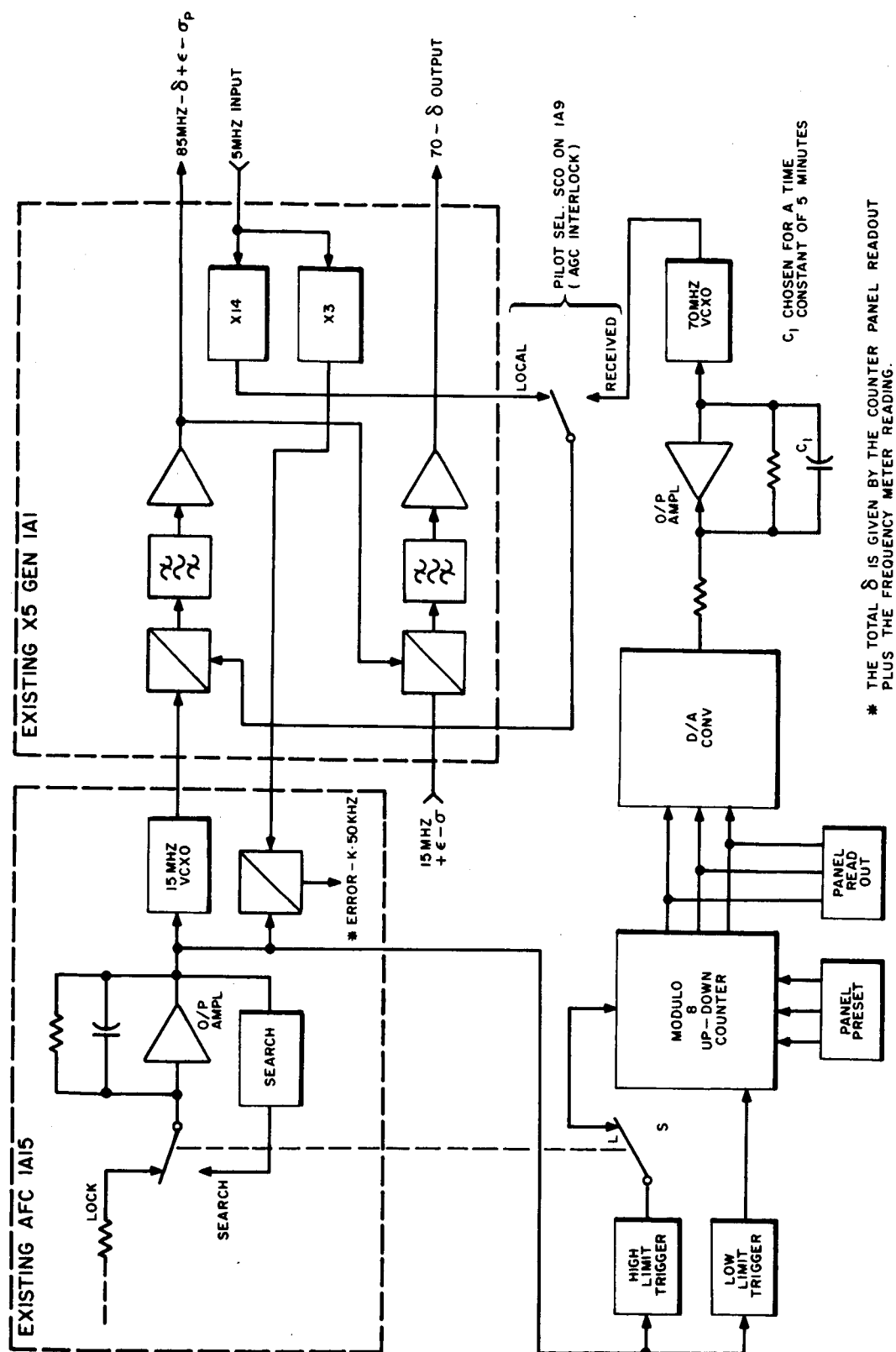Figure 2.   Typical Automatic Carrier-Offset Correction Cycle, Time Chart

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Figure 3. Implementation of Initial Study Showing Addition to Existing AFC System, Block Diagram

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The system would derive its switching command from the voltage applied to the 15 mc VCXO. If this reached a value such that the deviation in either direction exceeded 35 kc, the appropriate trigger would fire, adding one to the counter total. The D/A converter would change the counter output to a voltage, which would be arranged so that after passing through the low pass amplifier each voltage step would change the VCO frequency by 60 kc. Set and reset provisions for the counter would be brought to the panel for preset operations. The control could be located on the console.

The following are tentative specifications on the VCO:

Center frequency	70.000 mc at 5.0 volts
Mod. sensitivity	30 kc/v over 360 kc
Linearity	Not too important
Stability (all causes)	1 part in 10^5
Noise	0.7 cps rms maximum

The required circuitry for this system could be located in unit 1A15 if the operational amplifier, detectors, and flip-flop were comprised of micro-circuits. From an engineering time viewpoint this might also be a useful approach, since little design work would be required. The large capacitor required for the five minute time constant has a mounting bracket already located in the unit, and space would merely have to be found for the VCXO. It should be noted that success of this scheme is primarily dependent on availability of the 70 mc low noise VCXO.

B. Alternative Solutions.

Several approaches to the solution of these problems have been examined. The first is to simply increase the range of the 15 mc VCXO already in the system. This approach suffers from several problems. First, the search range would have to be increased and thus would take longer; 8 minutes for

the synchronous spacecraft and 4 minutes for a medium altitude system. Secondly, if the same loop gain (60 db) were maintained, a maximum error of ±180 cps would occur, which is greater than the ±100 cps that the Fp Rx pilot filter will pass. The filter cannot be made wider because of noise considerations. If the loop gain were increased to reduce the ±180 cps error to a workable number, the time constant of the afc loop would have to increase by a factor of three, and would become physically very difficult. The conclusion is that this approach is too cumbersome and difficult to be used.

A second approach is to use the existing afc to track over a ±30 kc range, and use a series of fixed frequency carriers to move the range in 60 kc increments. An alarm would indicate when the afc is nearing its limit, and the operator would switch to the next higher (lower) range of basic carrier frequency. The switch could also be made automatic by use of an up-down stepping switch or other arrangement. This system is workable and will function if it is permissible to lose contact with the spacecraft during changeover to the next frequency range, since the system goes out of lock due to a 30 kc step change in frequency. The system will have to search and lock on once more, taking a minute to do so, and service would be interrupted for this period. Clearly, this is not a desirable situation for a communications system, but this approach is simple and relatively inexpensive to implement.

In order to avoid the problem of falling out of lock when range is changed, the system must be made to shift range in a continuous, slow manner that will allow the afc closed loop to stay in lock and tracking during the transition period. This cannot be done by switching on one of several oscillators, but must be accomplished by slowly varying the frequency of the carrier generated by a single oscillator. Analysis of the Initial Design Study, Section 3.A., indicated that the maximum frequency slewing rate is 167 cps, giving a time of 5 minutes for a 60 kc range change to take place.

In order to change frequency in a slow, continuous manner the use of a VCO driven by a ramp is a reasonable choice. This VCO, however, must have good noise performance coupled with wide deviation capability. The

15 mc VCXO used in the present afc is at about the state of the art for crystal VCO's. It has an rms noise deviation of about 0.6 cps, and a pulling range of about 100 kc. It does not appear feasible to get more pulling range without more noise deviation.

In conjunction with this study program, the possibility of using an LC-type of VCO was investigated. Analysis indicated that a 300 kc pulling range was not incompatible with a 1 cps RMS noise deviation (Refer to Appendix I), and the oscillator was then designed and built. The pulling range was found to be close to 300 kc, and the rms noise deviation was found to be 0.87 cps, giving a total carrier noise deviation of 1.05 cps rms when added to the 0.6 cps rms component of the 15 mc VCXO.

C. 70 Mc VCO Design Study.

As pointed out in the initial study, the primary obstacle to final recommendation of the proposed scheme is the availability of a 70 mc voltage controlled oscillator, with a pulling range of 300 kc and with an rms deviation of less than 1 cps.

Because of the pulling range requirements, a crystal oscillator could not be used due to close spacing of the series and parallel resonances of the crystal.

An LC type of oscillator was thus indicated, but the requirements on it are very difficult. It was assumed permissible to build an oscillator at some frequency lower than 70 mc, and then beat it up to 70 mc with a crystal reference.

Previous Raytheon studies of short term stability measurements for oscillators have related the rms deviation and pulling range in an oscillator to be given as:

$$\Delta = 4 f_p \sqrt{N/P}$$

where Δ = the RMS deviation

f_p = the pulling range

N/P = the noise-power ratio in the oscillator

The noise is given by N = FkTB

where F = the noise figure of the amplifier stage in the os-
cillator

B = the bandwidth over which the rms deviation is
measured

For our application, the bandwidth is 90 cps, so

N = F - 154.5 dbm

for Δ = 1 cps, f_p = 300 kc

P (dbm) = F - 33.0 dbm

Thus, for a low noise figure, an oscillator level of at least -30 dbm is required at the input to the active device.

This same oscillator study also gives a formula for rms deviation as a function of tuned circuit Q and center frequency.

$$\Delta = \frac{f_o}{Q} \cdot \sqrt{N/P}$$

For the 70 mc VCO $\sqrt{N/P} \approx 8 \cdot 10^{-7}$, $\Delta = 1$, then the Q of the oscil-lator tuned circuit must be given by

$$Q \geq f_o \left[8 \cdot 10^{-7} \right]$$

A Q of 20 is easily realized, requiring an oscillator frequency of less than 25 mc.

In order to obtain a low noise figure at a high impedance level, an FET type of oscillator was tried. Figure 4 shows a simplified schematic of the oscillator. The transistor effectively raises the g_m of the FET, multiplying it by β.

The requirement for oscillation is that

$$(C_1 + C_2) \; \omega_o \; \leq \; \beta g_m Q_L$$

where

ω_o = the center frequency (radians)

Q_L = the Q of the inductor

g_m = the transconductance of the FET and

β = the current gain of the transistor.

For the devices used, βg_m is about 4×10^3 μmhos. This allows $(C_1 + C_2) \leq$ 520 pf. For safety, this was halved.

The oscillator was built as shown in figure 5. The varicap is a VR-100 type, and the series and shunt capacitors are chosen to give the proper tuning range.
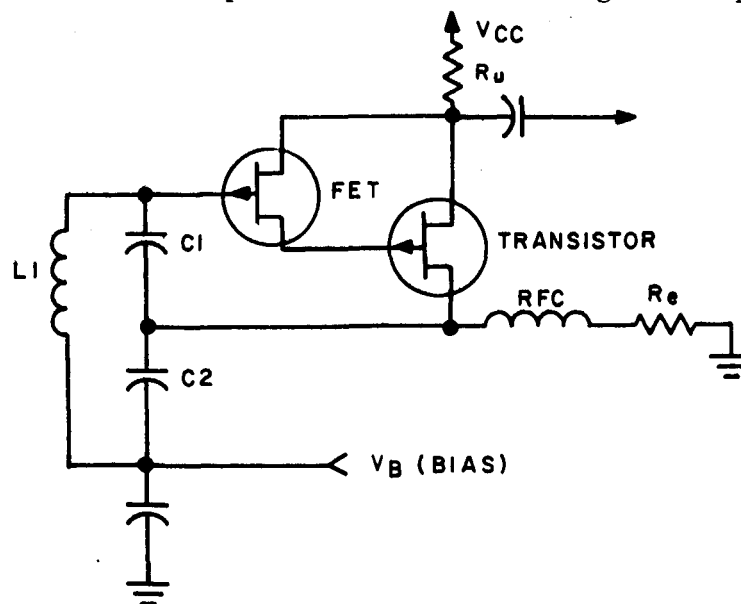

Figure 4. FET Type of 25.5 Mc Oscillator,
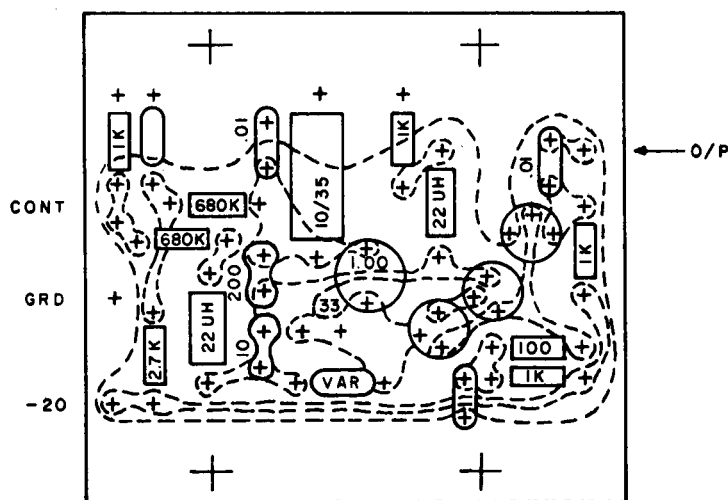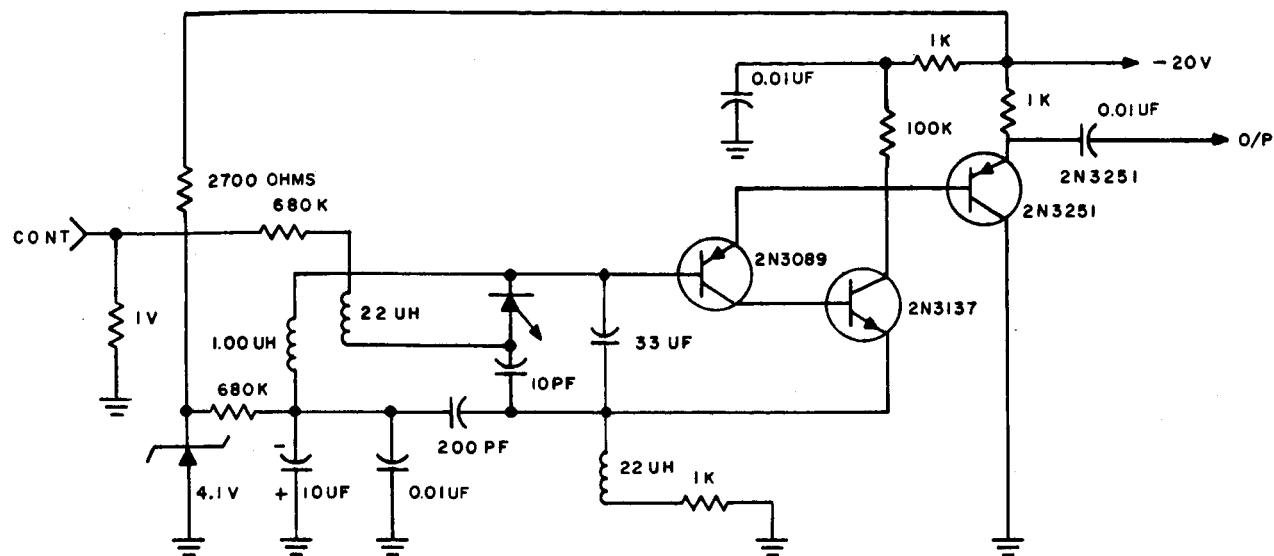Simplified Schematic Diagram

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Figure 5. FET Type 25.5 Mc Oscillator, Schematic
Diagram and Panel Assembly

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The oscillator was operated at +24 volts and worked very well. It was tuned to 25.5 mc, because a 25.5 mc crystal was available. This crystal was used in a 25.5 mc crystal oscillator which was beat down with the 25.5 mc VCO to give about 10 kc.

The 10 kc beat note was spectrum-analyzed with a Rohde & Schwarz type FNA spectrograph. The spectrum obtained was analyzed to give the rms deviation of the beat note. The type FNA has a bandwidth of 10 cps, requiring a 10 db correction when plotting power spectral density. It is assumed that all deviation is due to the VCO, since deviation from the crystal oscillator should be very low. Deviation on a similar crystal oscillator at 90 mc was only 0.015 cps rms, indicating that this is a good assumption.

Figure 6 shows two spectrograms of the beat note, showing the effect of hum on the control input line. Figure 7 shows a re-plotting of the spectra of figure 6 on semilog paper. Note that the points form a straight line with a slope of -30 db/decade.

The rms deviation is found to be 0.87 cps rms, which is inside the specification enough to be very encouraging. Further optimization of the design should be possible, making this type of oscillator very attractive.

Several curves were taken under various conditions of control voltage, and all agreed with those shown on figure 6.

A spectrum was run using the test equipment used to evaluate C/N for the ATS SSB transmitter, and the results agreed with 10% of those quoted here. This indicates that either measurement approach is adequate.

Figure 8 shows the frequency deviation as a function of control voltage of the VCO. It is shown to deviate easily over the required range.

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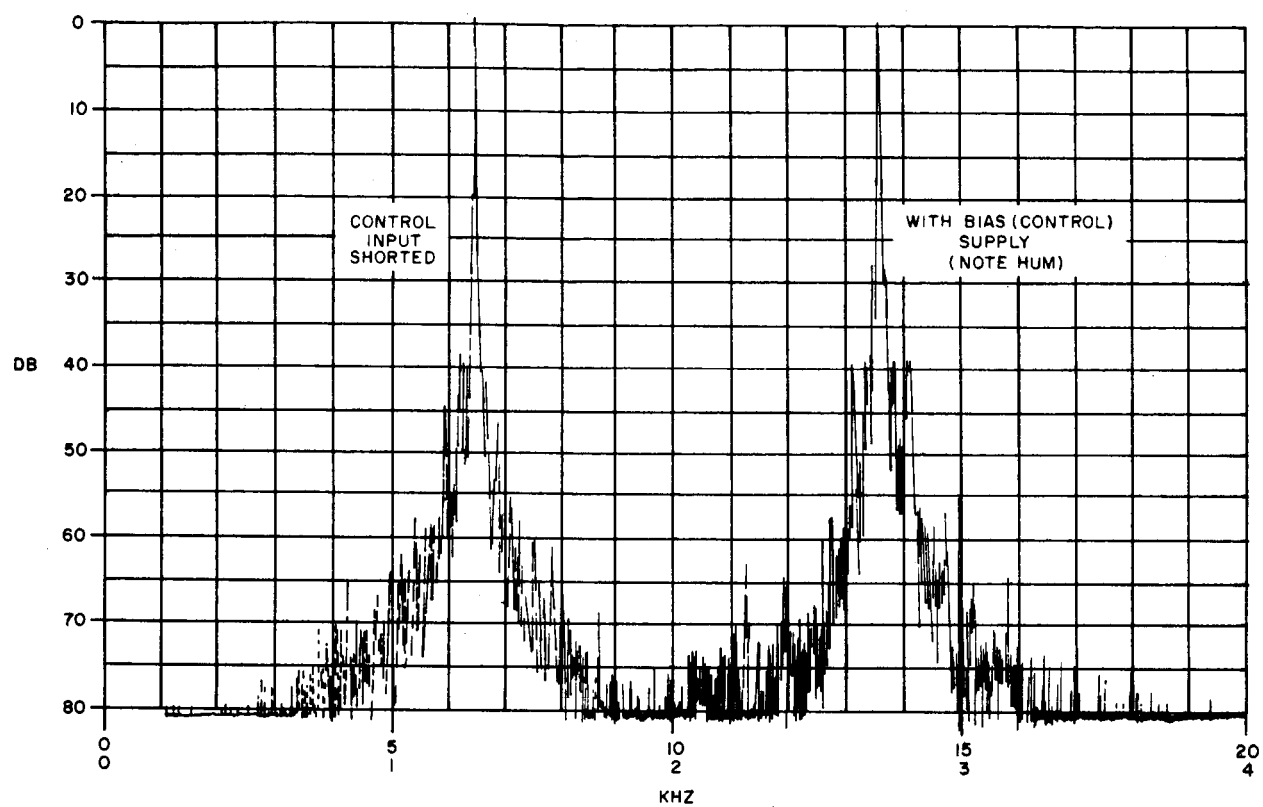
Figure 6. Two Spectrograms of Beat Note Showing Effect
of Hum on VCO Control Input Line

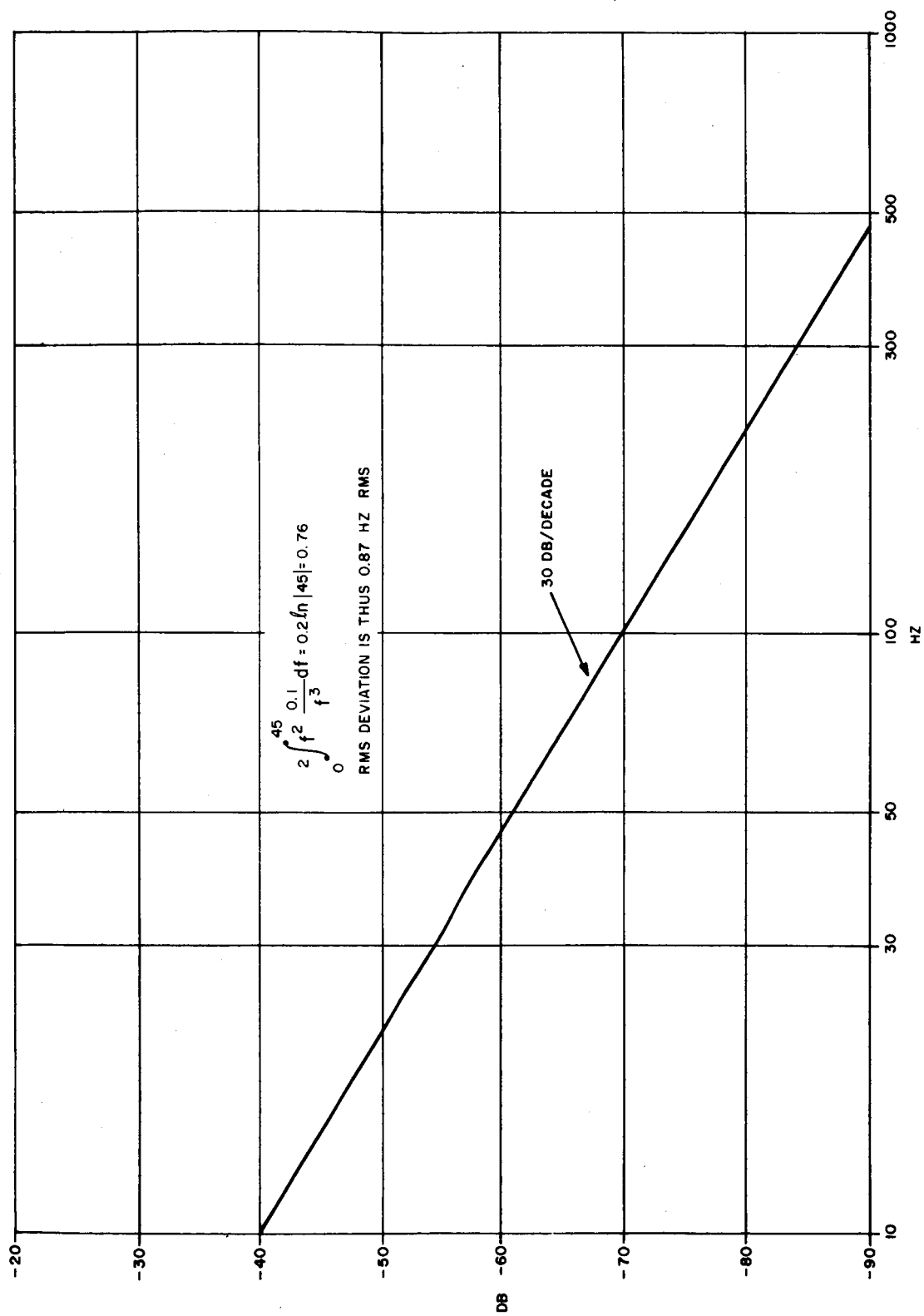18

$$2 \int_{0}^{45} f^2 \frac{0.1}{f^3} df = 0.2 \ln |45| = 0.76$$

RMS DEVIATION IS THUS 0.87 HZ RMS

30 DB/DECADE

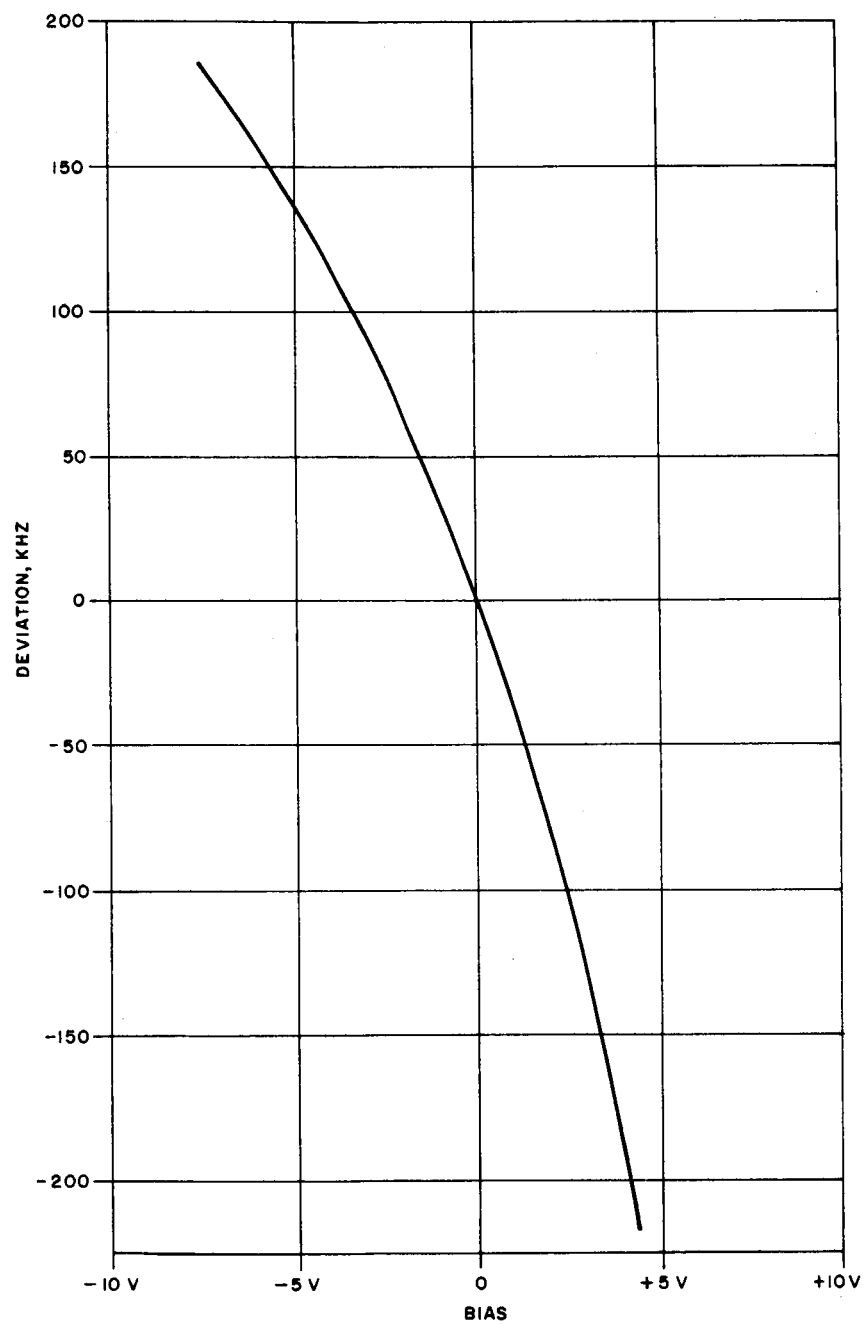HZ

DB

Figure 7. Calculations of RMS Deviation

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Figure 8. Frequency Deviation as a Function of the VCO Control Voltage

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There are several factors which must be carefully considered when this VCO is finally designed. Temperature stability is poor, hence a proportional oven is a necessity. Variations in power supply voltage will affect frequency and must also be removed by a regulator.

A third factor is microphonics. The oscillator is extremely sensitive to shock or vibration, since the tuning coil and capacitors change value slightly when vibrated. This effect is very small, but causes trouble even though it is of the order of one part in 10^6. Careful mounting of the oscillator is thus a problem, but if packed in foam rubber inside the oven, and if attention is paid to selecting parts, the VCO should give adequate performance. The only problem might be in pulling out the drawer in which the VCO is mounted while the afc loop is locked which could knock it out of lock. It might be necessary to install some delay in the search relay circuit to prevent loss of lock and initiation of search if a transient such as this occurs.

The feasibility of a wide-deviation, low-noise VCO has been shown, and although several problems in unit location and interconnection remain, the modification of the afc for a wider frequency range appears fairly straight-forward.

4. RECOMMENDATIONS

A. Proposed Solution.

Figure 9 shows the proposed implementation for the range extension method of the ATS afc System. The units to be added are shaded.

Two limit detectors are arranged so that one gives a pulse when the 15 mc VCXO requires more than +35 kc of correction; the other pulses when more than -35 kc of correction is required. The pulse generated makes a mod 8 binary counter count up if more than +35 kc is needed. The output of the counter is converted into a voltage in a simple D/A converter. This voltage will move up or down in steps as the counter counts up or down. Controls on the console permit presetting the counter to any one position to permit rapid acquisition of the spacecraft during the search phase. This preset capability allows acquisition of a spacecraft in a minimum time, about one minute for the medium altitude case and about two minutes for the synchronous mode. If the location in frequency of the spacecraft is not known to within 60 kc at the time of search, the search can take as long as 40 minutes. Some procedure must, therefore, be devised for finding the offset frequency to the nearest 60 kc so that the system can lock in quickly.

The voltage at the output of the D/A converter is then applied to an operational amplifier connected to give a low pass characteristic with a time constant of five minutes. This provides a ramp-like signal to the 70 mc VCO with a slow enough change to allow the afc loop to stay in lock.

The VCO is made up of a 21 mc VCO and a 49 mc crystal oscillator beating to give 70 mc. The rms noise deviation and pulling range are completely a function of the 21 mc oscillator, since the rms deviation of the crystal oscillator is less than 0.02 cps.

To achieve stability, the VCO is constructed of high-stability parts, such as glass or ceramic core inductors, metal-glaze resistors, and glass-ceramic capacitors. In addition, the VCO is housed in a proportional oven,
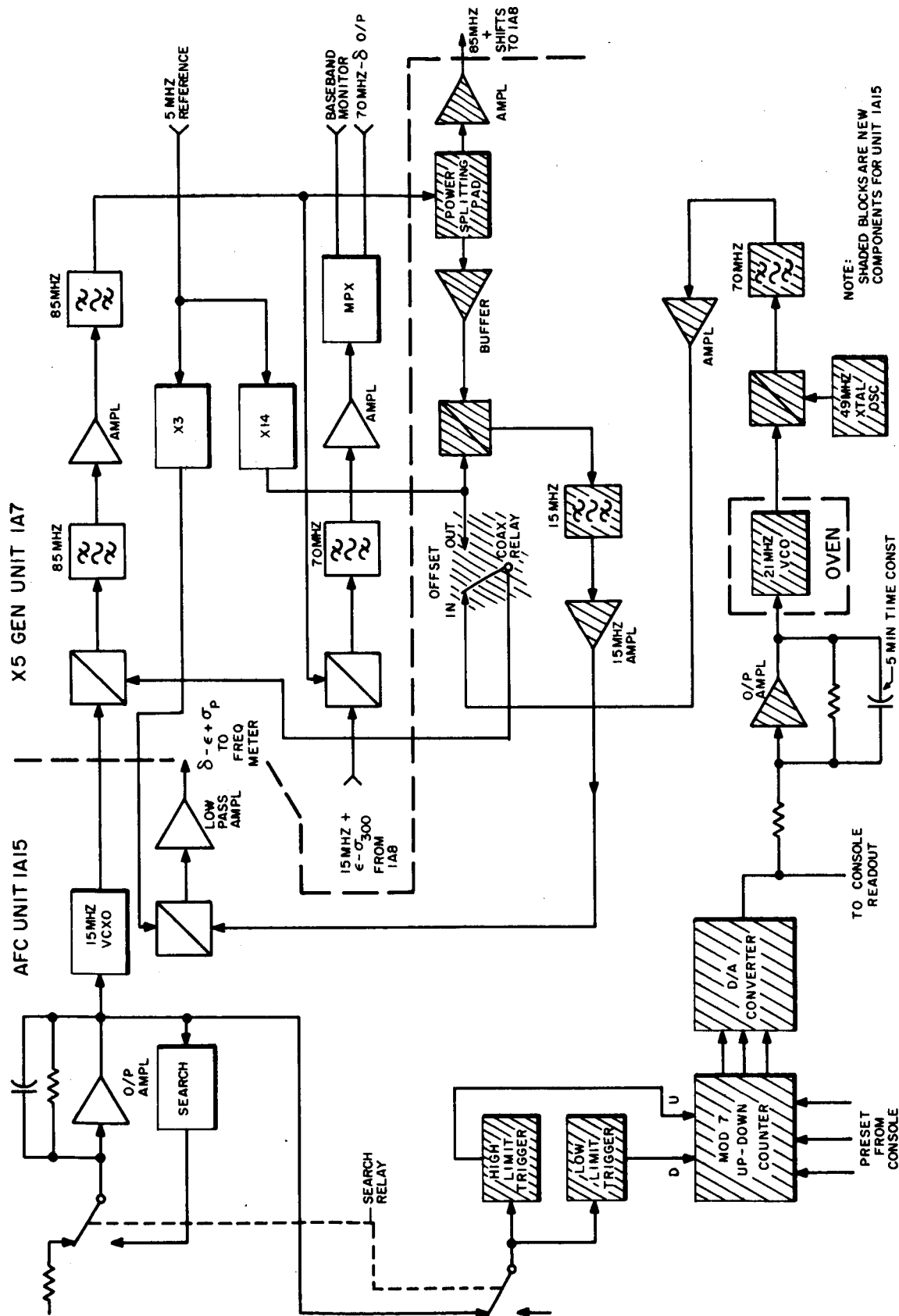
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Figure 9. Proposed AFC Range Extension Method, Block Diagram

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and the oscillator power supply is individually regulated. The stability of the VCO should be such that it will change frequency by less than 10 kc in a day.

The 70 mc output of the VCO circuit is then fed into the ATS SSB 1A7 unit in place of the fixed 70 mc generated there. This produces an 85 mc carrier that is offset by the shift on the VCO plus the shift on the 15 mc VCXO. This 85 mc carrier is used in unit 1A8 to shift the FDM information to the 70 mc IF frequency, and will thus place the VCO and VCXO shifts on the SSB signal.

The 85 mc carrier is also mixed with a pure 70 mc carrier to give a 15 mc signal with the combined shift on it. This 15 mc signal is then mixed with a pure 15 mc carrier to give just the total carrier shift which is sent to the console frequency meter.

A coaxial relay allows insertion of a pure 70 mc carrier in place of the VCO-derived carrier for testing and alignment. This approach to the afc range-extension problem contains several alternatives. For instance, the up-down counter could be replaced by a technician who would manually change the voltage at the input to the low pass amplifier as indicated by the alarms connected to the high and low limit detectors. The automatic approach was chosen because for a small increase in complexity, the technician is freed from this chore.

Another set of alternatives involves reduced utilization of the frequency meter. A large amount of circuitry would be eliminated if the frequency meter simply measured the frequency difference between the 15 mc VCXO and a pure 15 mc, as it does in the present system. This number could then be added (or subtracted) from the setting of the counter as shown on the console to give the total offset. The problem with this is knowing when to add and when to subtract and in addition, those 60 kc steps may really be 60 kc ±5 kc. For these reasons, the chosen approach is to detect the total shift and display it as such.

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B. Implementation

The console will have three controls and a meter added to it. The meter will indicate the state of the counter by indicating which 60 kc segment is being covered. Two of the controls will be pushbuttons to make the counter count up or down, one count per push. The third control will be a switch to activate a coaxial relay in unit 1A15 to switch in a pure 70 mc carrier, instead of the VCO, for testing purposes.

All circuitry for the modifications will be contained in unit 1A15, the afc unit. Unit 1A15 has spare connector mounting holes on both front and back panels, and has space for two 15-inch shielded modules to contain circuitry.

Figure 10 shows one possible approach to packaging the required circuitry in these modules. 1A15A3 tentatively contains the modulo 8 counter, the D/A converter, the low pass amplifier, and the 49 mc crystal oscillator and mixer for producing 70 mc. Unit 1A15A4 contains the high/low limit triggers and the frequency meter driving circuitry.

Microcircuit techniques must be used to conserve space in the modulo 8 counter and the operational amplifier circuitry. These applications are well developed and components are available off-the-shelf.

The VCO is housed in a proportional oven to maintain the $65^{\circ}C$ required for stability. Foam rubber packing and rubber shock mounts are used to reduce microphonic effects.

The VCO is mounted by moving module 1A15A5 toward the bottom of the unit and placing the VCO above the filter crystal oven. Filter crystal accessibility will be limited, but access to the crystal is not required on a regular alignment basis.

◄——— 5.5" ———►	◄——— 3.5" ———►	◄——— 4" ———►	◄— 2" —►

IAI5A3

MODULO 8 BINARY UP/DOWN COUNTER	D/A CONVERTER AND LOW PASS AMPL	MODULATOR 70 MHZ FILTER 70 MHZ AMPL	49 MHZ XTAL OSC

◄— 3.5" —►	◄— 2.0" —►	◄1.5"►	◄— 3.5" —►	◄——— 4.5" ———►

IAI5A4

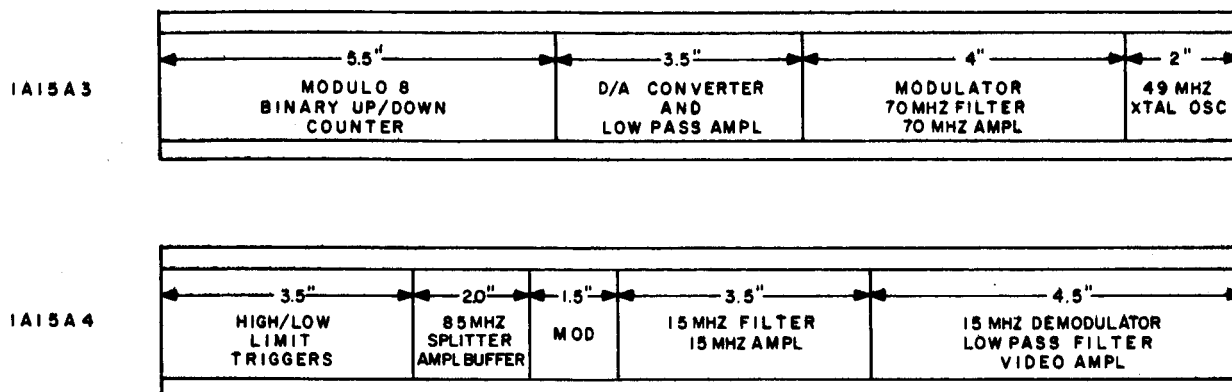| HIGH/LOW LIMIT TRIGGERS	85 MHZ SPLITTER AMPL BUFFER	MOD	15 MHZ FILTER 15 MHZ AMPL	15 MHZ DEMODULATOR LOW PASS FILTER VIDEO AMPL

Figure 10.   Proposed Layout of Subunits 1A15A3 and 1A15A4

The search range on unit 1A15 must be changed to provide the same range on synchronous and non-synchronous modes. This can be accomplished by means of a resistor value change. Approximately six new wires must be added between the SSB exciter and the console. Since there is no room for them to get into 1A15 through the present back panel power plug, this connector must be enlarged or a second connector added. Connectors must be added to the top of the exciter and console cabinets, and a cable must be connected between them carrying at least six wires.

The coaxial relay should be mounted in unit 1A15, but if space is not available, it could be moved to unit 1A7 (X5 generator) or even attached to the exciter cabinet. Unit 1A7 will require two new back panel connectors to allow the 70 mc carriers to pass between 1A15 and 1A7.

New cables are required for rack front and back wiring and for exciter rack interconnection with the console. The console frequency meter is moved from the center of its slot to the left side. The new afc operating controls and counter readout are placed in the newly available space. About five inches of panel is liberated by this procedure, which should be adequate. Figure 11 shows a tentative arrangement of these controls.

Acceptance of the system modification by NASA is dependent on a demonstration that the new VCO has an rms noise deviation of less than 0.8 cps, and that exceeding the limits on the VCXO control voltage causes the 70 mc carrier supply to move by 60 kc increments with a five-minute time constant. The spurious outputs on the 70 mc carrier output will be shown to be a minimum of 70 db below the carrier in the band from 64.4 mc to 75.6 mc, and a minimum of 40 db down elsewhere.

C. Installation.

The modifications are recommended to be performed in the field with a kite provided for that purpose, with the exception that unit 1A15 is to be returned to Raytheon for modification and installation of the new circuitry.
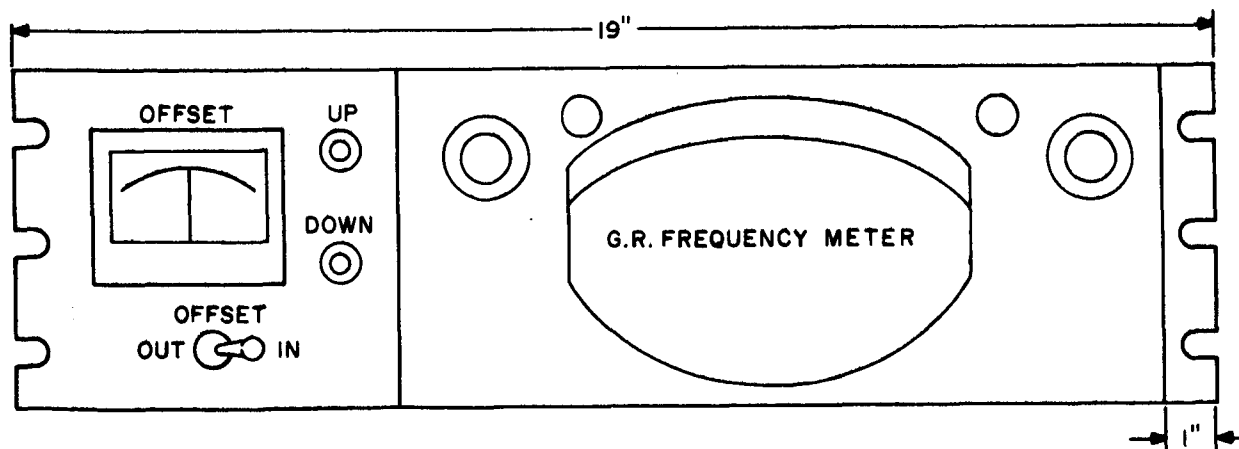

Figure 11. Proposed AFC Offset Control Panel

APPENDIX I

TELEGRAPH DISTORTION AND RMS DEVIATION

The CCITT supplement on telegraph transmission (page 251-262 of Red Book, Volume VII, dated March 1961) states (on page 253) that the tolerable distortion is 12% and that this corresponds to a noise power of 2×10^6 pw. Previously a value of 10% for a "single contributor" has been used in our calculations. The noise power is then about 1.5×10^6 pw.

From this level of noise power the rms deviation can be calculated using the formula:

$$d = \frac{No}{2C} \; f^3$$

No = Noise power density = $1.5 \times 10^6 / 3 \times 10^3$ = 500 pw

C = Carrier power = 22 db below 10^9 pw

f = 1/2 channel bandwidth = 45 cps

d = 1.9 cps rms

For a multi-contributor system the rms deviation can increase to 5.3 cps or the distortion can be 28%. It should be noted that regenerators can be used when the distortion is as high as 40%.

The system performance should be designed to be better than the 28% distortion value.